

TECHNICAL PROGRESS REPORT

Title:	APPLICATION OF ADVANCED RESERVOIR CHARACTERIZATION, SIMULATION, AND PRODUCTION OPTIMIZATION STRATEGIES TO MAXIMIZE RECOVERY IN SLOPE AND BASIN CLASTIC RESERVOIRS, WEST TEXAS (DELAWARE BASIN)
Cooperative Agreement No.:	DE-FC22-95BC14936
Institution:	Bureau of Economic Geology The University of Texas at Austin University Station, Box X Austin, Texas 78713-7508
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OBJECTIVES

The objective of this project is to demonstrate that detailed reservoir characterization of slope and basin clastic reservoirs in sandstones of the Delaware Mountain Group in the Delaware Basin of West Texas and New Mexico is a cost effective way to recover a higher percentage of the original oil in place through strategic placement of infill wells and geologically based field development. Project objectives are divided into two major phases. The objectives of the reservoir characterization phase of the project are to provide a detailed understanding of the architecture and heterogeneity of two fields, the Ford Geraldine unit and Ford West field, which produce from the Bell Canyon and Cherry Canyon Formations, respectively, of the Delaware Mountain Group and to compare Bell Canyon and Cherry Canyon reservoirs. Reservoir characterization will utilize 3-D seismic data, high-resolution sequence stratigraphy, subsurface field studies, outcrop characterization, and other techniques. Once the reservoir-characterization study of both fields is completed, a pilot area of approximately 1 mi² in one of the fields will be chosen for reservoir simulation.

The objectives of the implementation phase of the project are to (1) apply the knowledge gained from reservoir characterization and simulation studies to increase recovery from the pilot area, (2) demonstrate that economically significant unrecovered oil remains in geologically resolvable untapped compartments, and (3) test the accuracy of reservoir characterization and flow simulation as predictive tools in resource preservation of mature fields. A geologically designed, enhanced-recovery program (CO₂ flood, waterflood, or polymer flood) and well-completion program will be developed, and one to three infill wells will be drilled and cored. Through technology transfer workshops and other presentations, the knowledge gained in the comparative study of these two fields can then be applied to increase production from the more than 100 other Delaware Mountain Group reservoirs.

SUMMARY OF TECHNICAL PROGRESS

Geophysical Characterization

Interpretation of the 3-D seismic survey that was shot for this project has been completed. The 3-D seismic volume indicates that Ramsey sandstone thickness in Ford Geraldine unit is 1/4 wavelength of the seismic data. The coherency cube is effective in delineating the field outline, and a residual map of the top of the Lamar Limestone identified a residual high that is associated with Ramsey sandstone thickness. The amplitude family of attributes had the highest correlations with the reservoir properties, especially porosity. The best correlation coefficients were less than 0.4 when all the wells were used, but higher correlations were found in smaller areas within the unit.

Reservoir Characterization

Geraldine Ford field produces from the upper Bell Canyon Ramsey sandstone in Reeves and Culberson Counties, Texas. Production from this and other upper Bell Canyon fields in the Delaware Basin occurs from the distal (southwest) ends of northeast-oriented linear trends of thick Ramsey sandstone deposits. The Ramsey sandstone is composed of a 0- to 60-ft-thick sandstone bounded by laminated siltstones. In the northern part of the field the reservoir is divided into two sandstones (Ramsey 1 and 2) separated by a 1- to 3-ft-thick laminated siltstone. In the southern part of Geraldine Ford field, only the Ramsey 1 sandstone is present. The underlying Ford and overlying Trap siltstones are composed of

organic-rich siltstone laminae interbedded on a millimeter scale with organic-poor siltstone laminae. The Ford and Trap siltstones display gradational contacts with fissile, highly organic siltstones interpreted as basinal condensed sections.

On the basis of core descriptions, log correlations, and study of an outcrop analog, Ramsey sandstones are interpreted as having been deposited by sandy high- and low-density turbidity currents. The sands were deposited in a basin-floor setting in a channel-levee system with attached lobes. Channel facies are approximately 1,200 ft wide and 15 to 35 ft deep. They consist of massive and crossbedded sandstones interpreted to have been deposited from high-density turbidity currents. Channel margins, characterized by rippled and convoluted sandstones interbedded with minor siltstones, are interpreted as channel levees formed by overbanking of low-density turbidity currents. Lobe sandstones are interpreted as being deposited at the mouth of the channel by high-density turbidity currents. They were identified by massive and graded sandstones with load and dewatering structures that include flame structures, dish structures, and vertical pipes.

Laminated Ford siltstones appear to coarsen upward because the organic-poor laminae increase in thickness toward the Ramsey sandstone. The overlying Trap siltstones appear to fine upward away from the sandstone as the organic-poor laminae decrease in thickness. This pattern suggests that the laminated siltstones are part of the progradation and retrogradation of the channel-levee and lobe system; the siltstones may represent the most distal part of the lobe. Alternatively, the siltstones may represent windblown silt from the shelf margins. Periods of relative sea-level fall may have exposed increasingly larger areas on the shelf and allowed the wind to carry away greater volumes of silt, resulting in thicker organic-poor siltstone layers.

Outcrop Characterization

The geometry and lateral continuity of important architectural elements for Bell Canyon sandstones were documented and a depositional model was developed. Stratal relationships indicate that upper Bell Canyon sandstones exposed in outcrop were deposited by high- and low-density turbidity currents in a basinal deep-water setting. The fundamental depositional element is the channel with attached levees and lobes. The depositional model developed from outcrop for this project can be widely applied by operators to other reservoirs that produce from Delaware Mountain Group sandstones.

Producibility Problem Characterization Recovery Technology Identification and Analysis

Simulations of Tertiary Recovery.—To estimate the tertiary recovery potential of the demonstration area in the northern part of the Ford Geraldine Unit (FGU), flow simulations were performed for a CO₂ flood. The results of these simulation will be used by Conoco, the Bureau of Economic Geology, and DOE to determine the feasibility of moving to Phase II, the demonstration phase.

The simulations were performed on a quarter-five spot in the demonstration area in the northern part of Ford Geraldine Unit. Stochastic as well as layered permeability distributions were considered. In the first simulations, reported previously, post-waterflood water saturation was assumed to be 63%. During this quarter, additional simulations were performed to improve the reliability of the results and to observe the sensitivity of the results to the following factors:

1. Increasing the residual oil saturation in oil/water relative permeability curves from 0.21 to 0.26.
2. Increasing the post-waterflood water saturation from 0.63 to 0.70.
3. Implementing a WAG (water alternating gas) flood in place of continuous CO₂ injection.
4. Reducing the vertical to horizontal permeability ratio from 1 to 0.1.

An increase in residual oil saturation in water/oil relative permeability curves does not appreciably affect the recovery (Fig. 1). However, according to the field experience of Conoco engineers, the adjusted water/oil relative permeability is more realistic. Therefore, for all the subsequent simulations, only this set of relative permeabilities was used.

The effect on oil recovery of increasing water saturation from 0.63 to 0.7 is shown in Figure 2. The higher initial water saturation results in early breakthrough, and ultimate recovery is reduced by 12 to 15% in the stochastic as well as the layered case of permeability distribution. However, these simulations indicate that even under these extreme assumptions, ultimate CO₂ flood recovery can exceed 30% of the remaining oil in place.

The recovery results from WAG simulations are compared to continuous CO₂ injection for the stochastic permeability case with 63% water saturation (Fig. 3). The simulation results suggest that the WAG process is slightly more efficient. However, the recovery time increases by about 50%, which may offset any gains in real terms. The WAG simulations could not be performed in the layered case because of numerical instabilities.

Figure 4 is a plot of oil recovery for the layered case with 63% water saturation for vertical to horizontal permeability ratios of 1 and 0.1. This figure shows that the reduction in vertical permeability causes slightly earlier breakthrough. The recovery remains lower in the intermediate region, but ultimate recovery is the same or even higher.

In summary, these simulations indicate that the CO₂ recovery results are adversely affected by increasing water saturation from 0.63 to 0.7. The recovery is not appreciably sensitive to adjustment of water/oil relative permeability or reduction in vertical permeability. The WAG process is slightly more efficient than continuous CO₂ injection, but it will take a longer time for oil recovery.

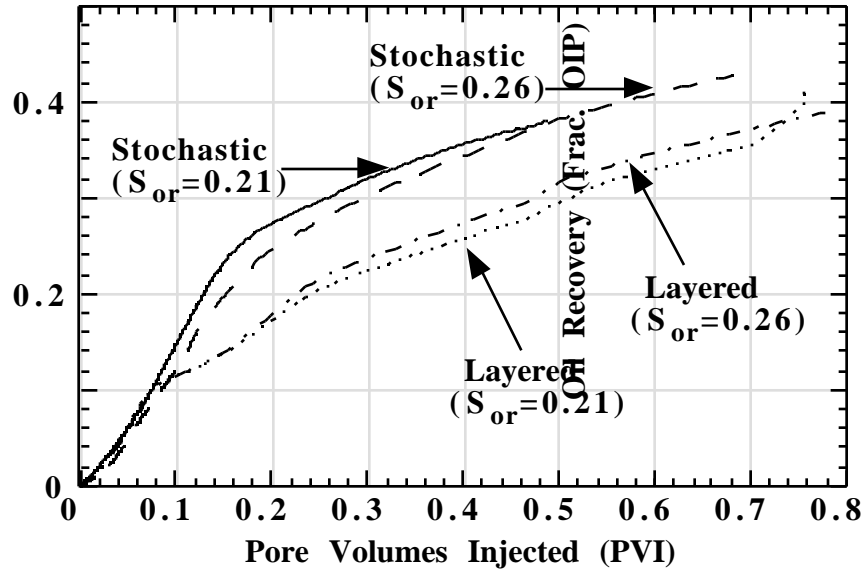


Figure 1. Oil recovery with adjustment in residual oil saturation.

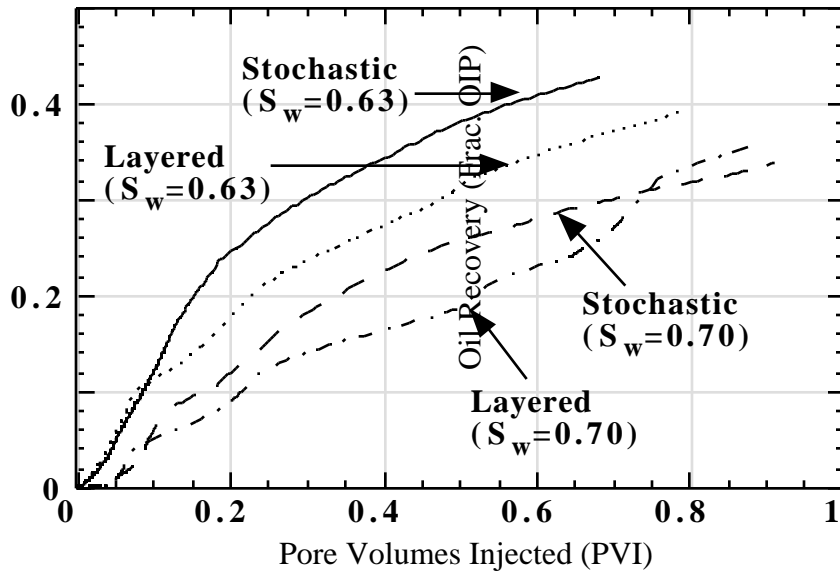


Figure 2. Oil recovery as a function of water saturation.

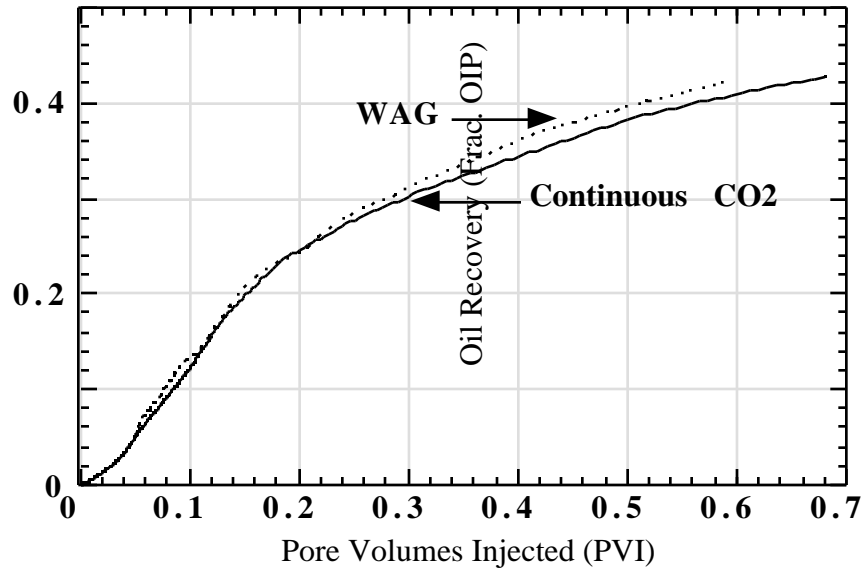


Figure 3. Oil recovery in WAG and continuous CO2 injection.

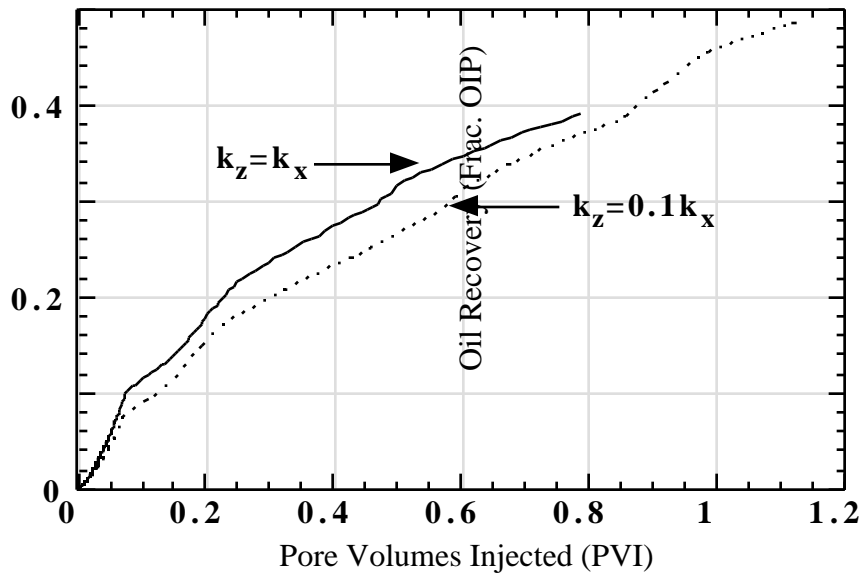


Figure 4. Oil recovery with reduction in vertical permeability.

Technology Transfer

Much of the focus of technology transfer this quarter was on preparation of a topical report that contains the preliminary data collected under Phase 1 of the project. In addition, preparations were made for a technology transfer field trip and workshop to be held Nov. 21-23 in Carlsbad, New Mexico. The trip will focus on (1) understanding the processes that deposited upper Bell Canyon sandstone and siltstone and (2) documenting the geometry, dimensions, facies, and composition of the fundamental architectural elements. Features viewed in Bell Canyon outcrops will be compared with characteristics of reservoirs in the Ramsey Sandstone, the producing interval in the Ford Geraldine Unit. Cores from Ford Geraldine Unit will be displayed.

The following talks will be presented at the Fall Symposium of the West Texas Geological Society in Midland, Texas on October 30, 1997:

Asquith, G. B., Dutton, S. P., and Cole, A. G., Delaware effect and the Ramsey Sandstone, Ford Geraldine Unit, Reeves and Culberson Counties, Texas.

Asquith, G. B., Dutton, S. P., Cole, A. G., Razi, M., and Guzman, J. I., Petrophysics of the Ramsey Sandstone, Ford Geraldine Unit, Reeves and Culberson Counties, Texas.

Dutton, S. P., Barton, M. D., Clift, S. J., Guzman, J. I., and Cole, A. G., Depositional history of Ramsey Sandstone channel-levee and lobe deposits, Bell Canyon Formation, Ford Geraldine Unit, West Texas (Delaware Basin): talk to be presented at the Fall Symposium of the West Texas Geological Society in Midland, Texas on October 30, 1997.

Dutton, S. P., Barton, M. D., Clift, S. J., Guzman, J. I., Asquith, G. B., and Cole, A. G., Application of advanced reservoir characterization to Ramsey Sandstone reservoirs, Ford Geraldine Unit, West Texas (Delaware Basin).

In addition, the talk "Petrophysics of the Ramsey Sandstone, Ford Geraldine Unit, Reeves and Culberson Counties, Texas," will be presented by George B. Asquith on November 12 at the Amarillo chapter of the Society of Professional Well Log Analysts, December 2 at The University of Texas at El Paso, and December 3 at New Mexico State University at Las Cruces.

PLANNED ACTIVITIES

Work in the next quarter will focus on (1) conducting the technology transfer workshop and field trip, and (2) completing an economic analysis of installation of the Phase 2 CO₂ flood in the pilot area.